Extreme High Vacuum

Marcy Stutzman, Ph.D. Jefferson Lab Center for Injectors and Sources

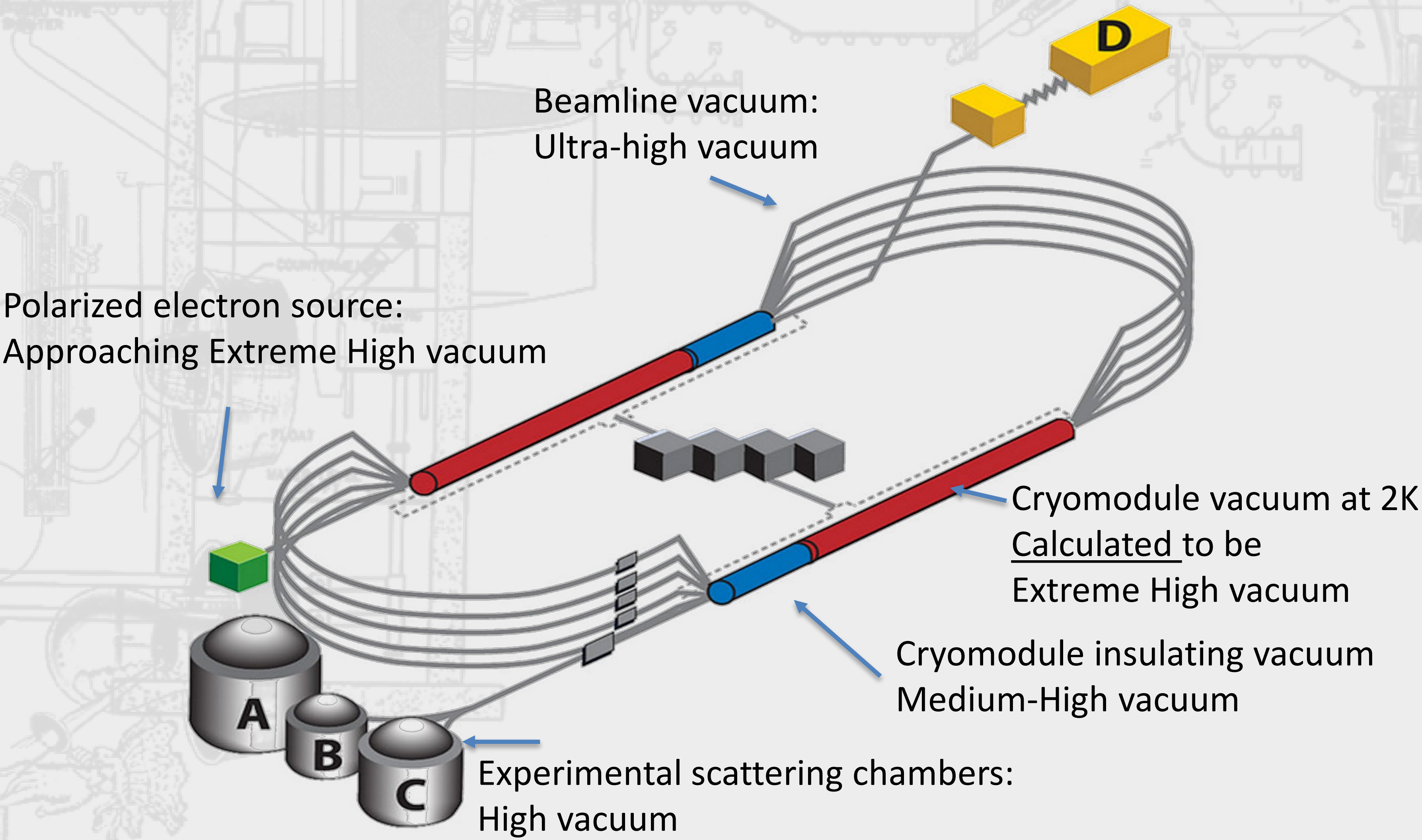
Thomas Jefferson National Accelerator Facility is managed by
Jefferson Science Associates, LLC, for the U.S. Department of Energy's Office of Science

Jefferson Lab

Outline

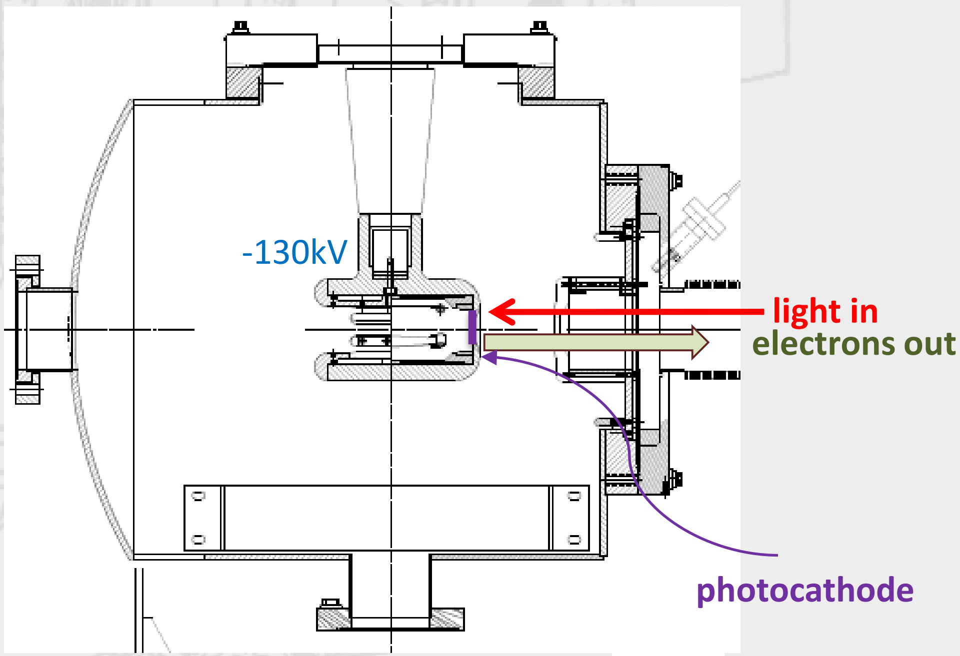
- Jefferson Lab
  - Polarized Electron Source
- Pumps
- Measurement
- Summary

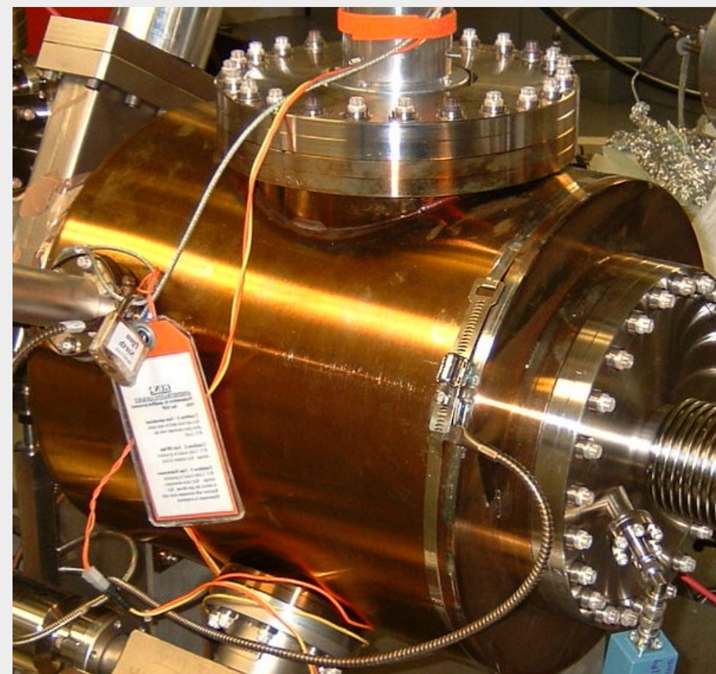
Jefferson Lab vacuum



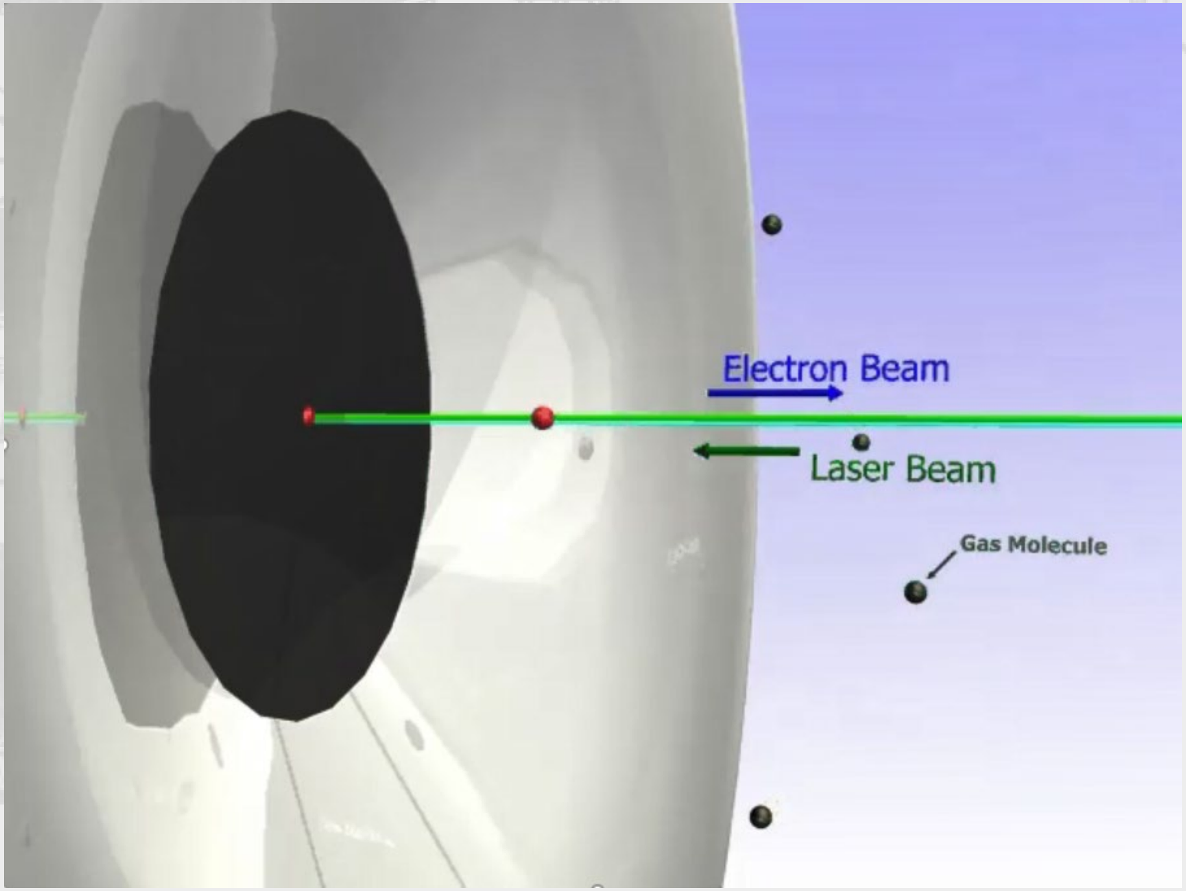
Photoemission Source

- -130 kV DC (*vs.* RF) electrode bias
- x-ray standard “inverted” insulator
- Pumps with NEG modules and ion pump
- Base pressure approaching XHV ≡ $P < 1\times10^{-12}$ Torr





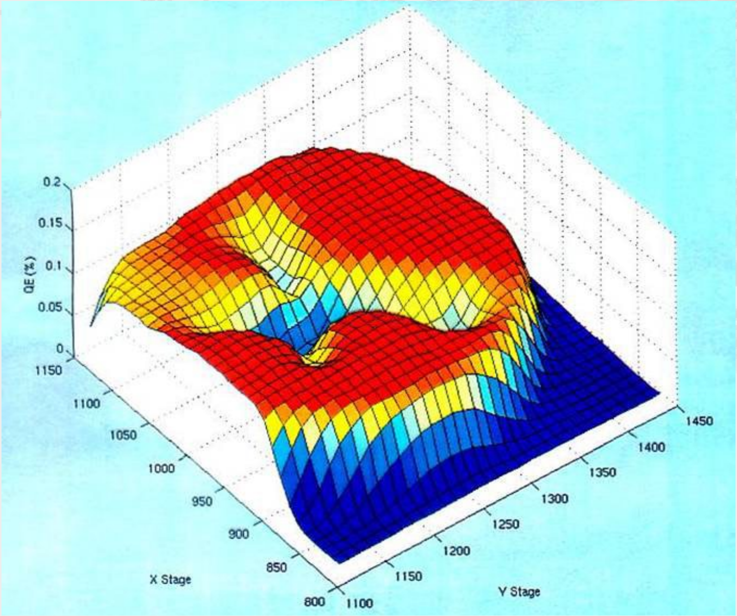
Any gas in chamber can be ionized by electron beam, accelerated back toward the photocathode and limit photocathode operational lifetime

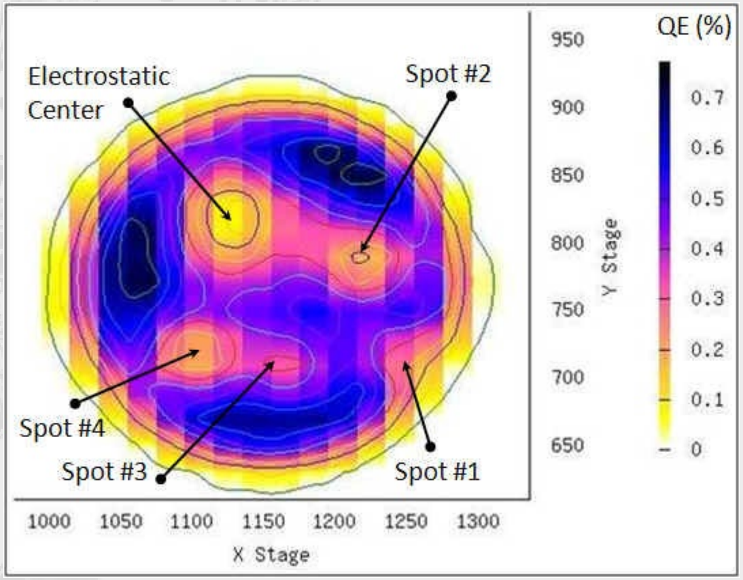


Photocathode Lifetime

- Ion bombardment – with characteristic QE "trench" from laser spot to electrostatic center of photocathode – **damages NEA** of GaAs
- High energy ions are focused to electrostatic center: create QE "hole"

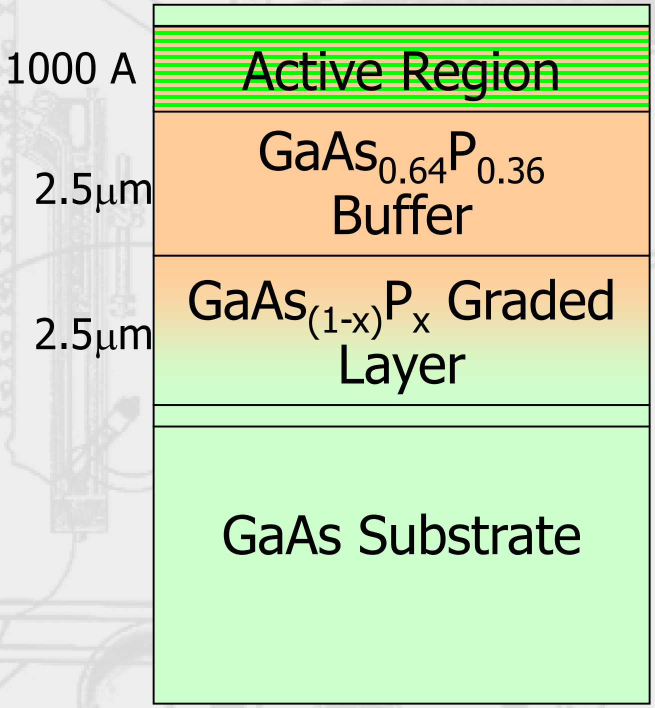
  Don't run beam from electrostatic center.
- QE can be restored, but takes about 8 hours to heat and reactivate

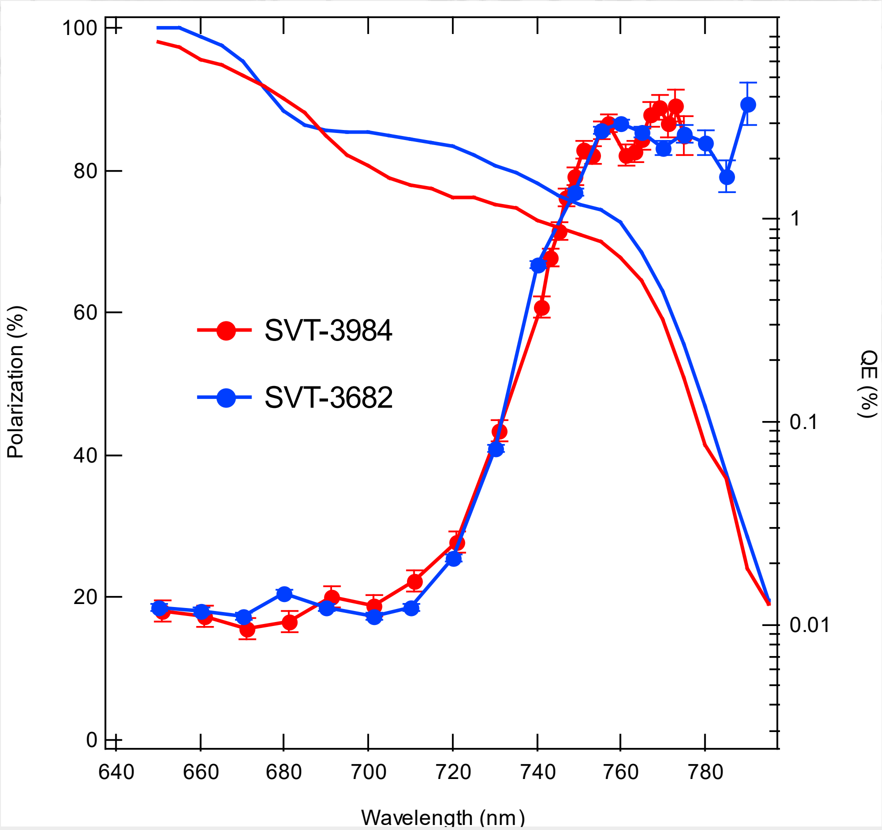




Strained-Superlattice GaAs/GaAsP

QE 1% and Polarization 85%



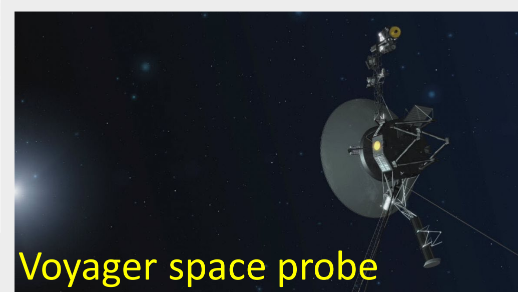


D. Luh et al, SLAC, PESP2002

From Aaron Moy, SVT Assoc and SLAC, PESP2002

Vacuum levels

	Example	Pressure (Torr)	atoms/cm^3
Atmosphere	Atmosphere at sea level	760	27,000,000,000, 000,000,000 or 2.7x10^{19}
Low vacuum (1-300 Torr)	Atmosphere on Mount Everest	252	1x10^{19}
	Pressure in bell jar experiment, Mars	1-10	1-3 x 10^{17}
Medium vacuum (1 Torr-1mTorr)	Insulating vacuum, atmosphere on Pluto	10^{-3}	10 quadrillion
High vacuum (1 mTorr- 1x10^{-7})	Scattering chambers	10^{-5}	100 trillion
Ultra high vacuum (UHV, 1x10^{-7} – 1x10^{-12})	Vacuum tubes, Cathode Ray tubes, beamline vacuum	10^{-8}	100 million
	Pressure outside Space Station (400 km)	10^{-10}	1 million
	JLab Electron Gun	10^{-12}	10,000
Extreme high vacuum (XHV <1x10^{-12})	Interstellar space estimate ~ 1 atom / cm^3	10^{-17}	1


Voyager space probe

Jefferson Lab

Mean free path

Pressure (mbar)	mean free path (m)
1.E+03	5.9E-08
1.E+02	5.9E-07
1.E+01	5.9E-06
1.E+00	5.9E-05
1.E-01	5.9E-04
1.E-02	5.9E-03
1.E-03	5.9E-02
1.E-04	5.9E-01
1.E-05	5.9E+00
1.E-06	5.9E+01
1.E-07	5.9E+02
1.E-08	5.9E+03
1.E-09	5.9E+04
1.E-10	5.9E+05
1.E-11	5.9E+06
1.E-12	5.9E+07

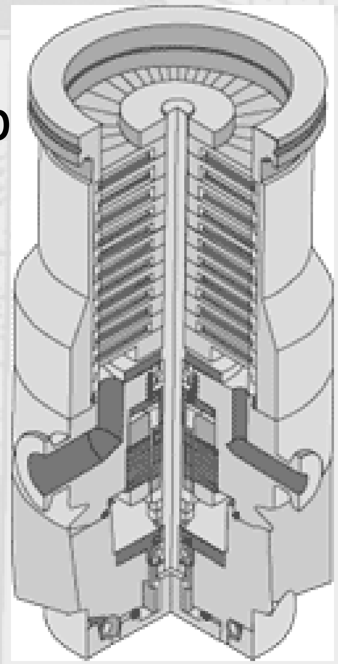
Without vacuum, 6 nm before collision

CEBAF linac vacuum: 6 to 60 km mean free path

Modern Vacuum Pumps

Gas Transfer Pumps

- Rotary vane pump
- Roots pumps
- Turbo pumps



Compress rarified gas
Move gas to higher pressure exhaust

Capture Pumps

- Ion pumps
- Getter pumps
- Cryopumps

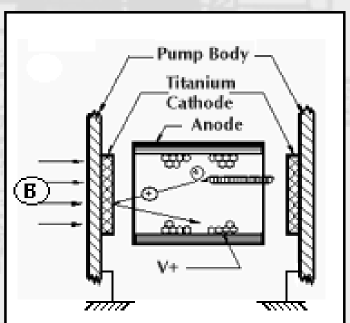
Remove molecules from *gas phase*

Jefferson Lab

Capture Pumping

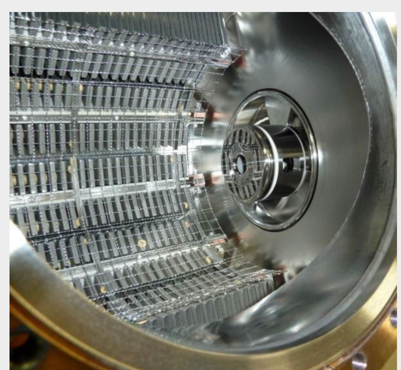
Ion pumps

- Gas ionized
- High voltage accelerates ions into plates
- Ion implant in plates - captured



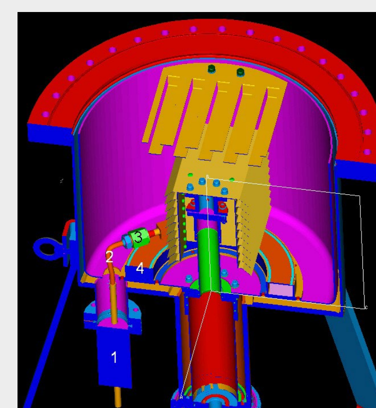
Getter pumps

- Chemically reactive surface
- Gas molecules incident on surface stick
- Chemisorption removes gas



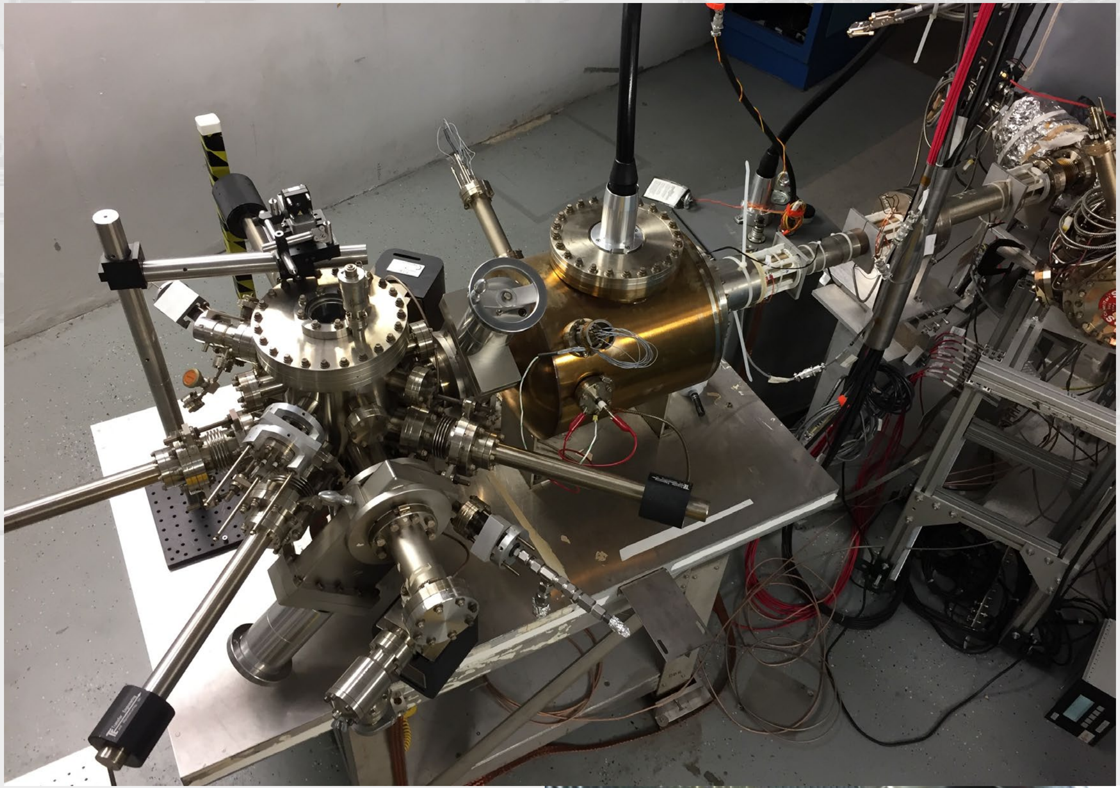
Cryopumping

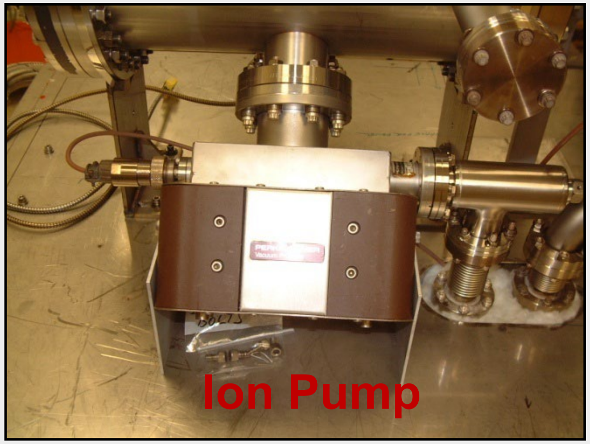
- Large surface area material
- Cooled below freezing temperature of desired gas
- Gas incident on cold surface sticks



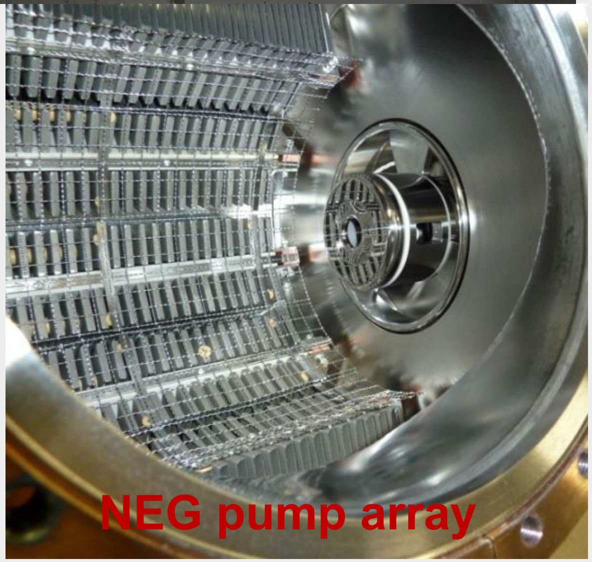
Achieving Extreme High Vacuum

- **Avoid contamination by oils due to roughing pumps, fingerprints, machining.**
- **Heat treat Chamber and components**
  - Reduces primary source of gas: hydrogen outgassing
- **Baking used to get pressures below 10^{-10} Torr**
  - 250°C for 30 hours removes water vapor
- **Non-Evaporable Getter Pumps**
- **Ion Pumps**



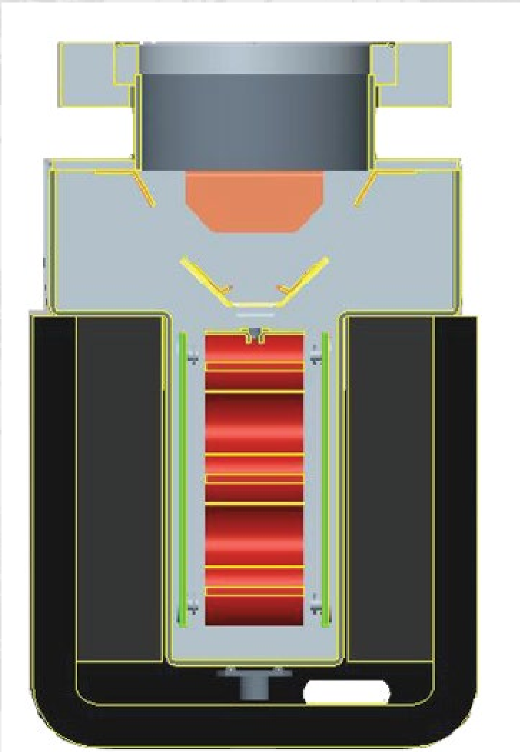


Ion Pump



NEG pump array

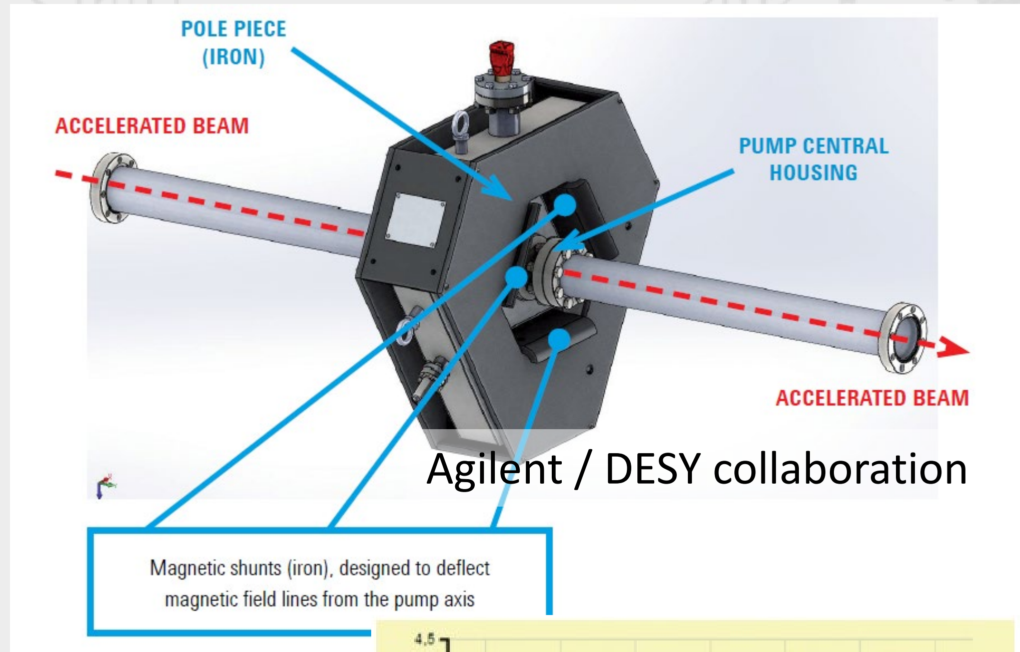
UHV pumping innovations



GammaVacuum / Edwards
“Eximo” shielding and heat treatment
CRADA collaboration with JLab

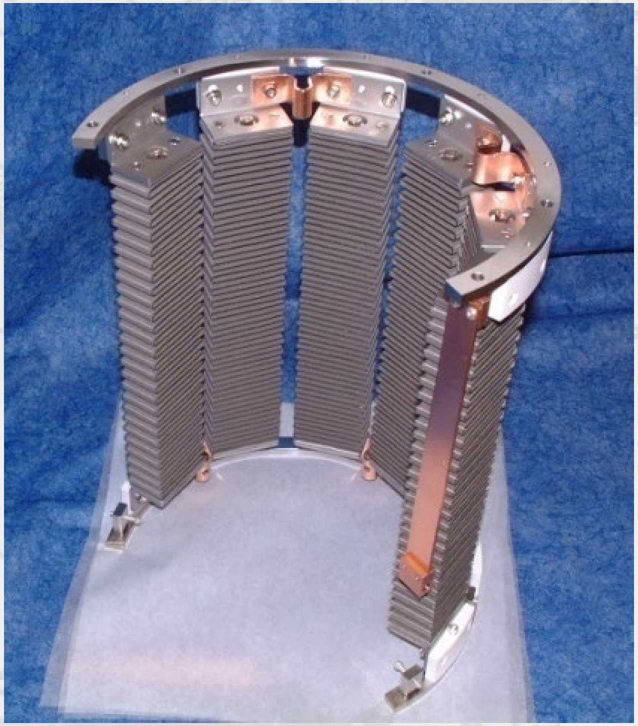
Shields (yellow) to minimize particles and gas leaving pump and entering chamber

Manufacturers working with customers to improve products



Agilent / DESY collaboration

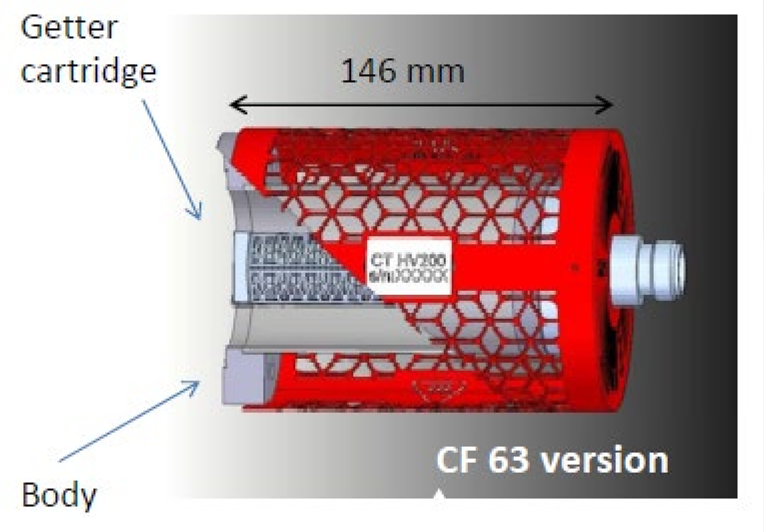
UHV pumping innovations

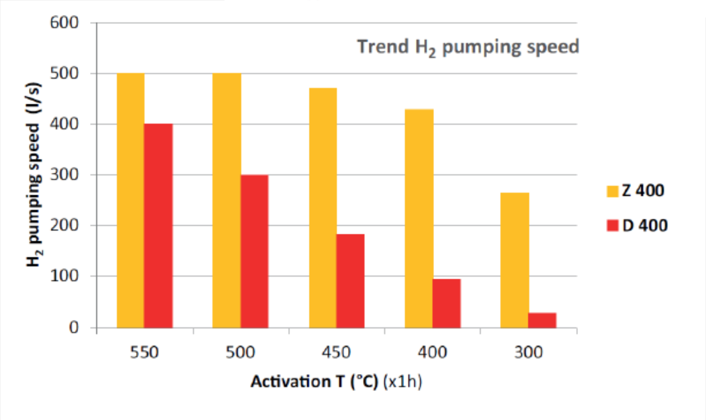


NEG pump developed
CERN and SAES ~1975

Reactive metal sintered to
resistive strips
Activate with 38A

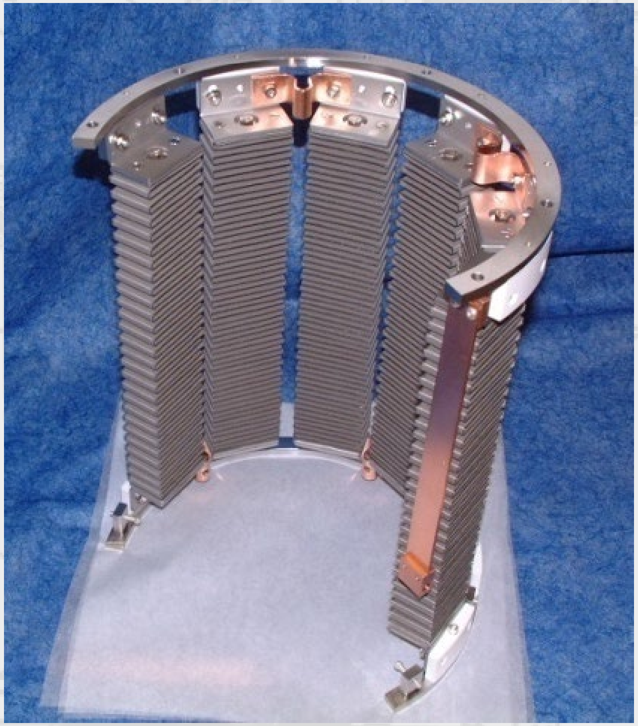
New alloy: Zr-V-Ti-Al “ZAO”

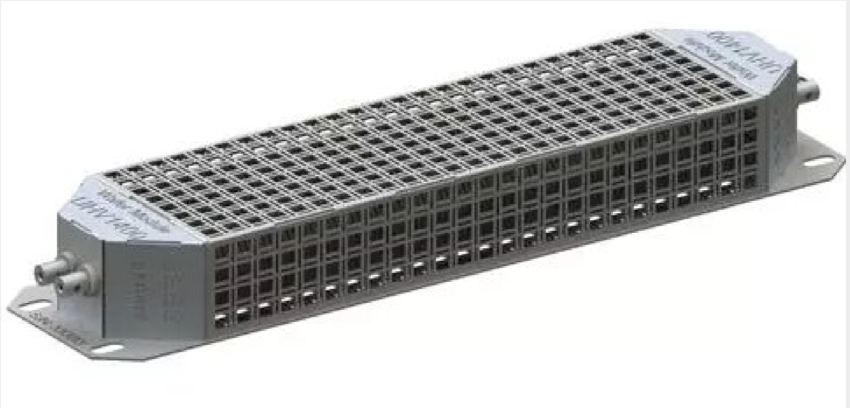




Lower activation temperature
Higher pump speed
Less dust generation

ZAO: Wafer module





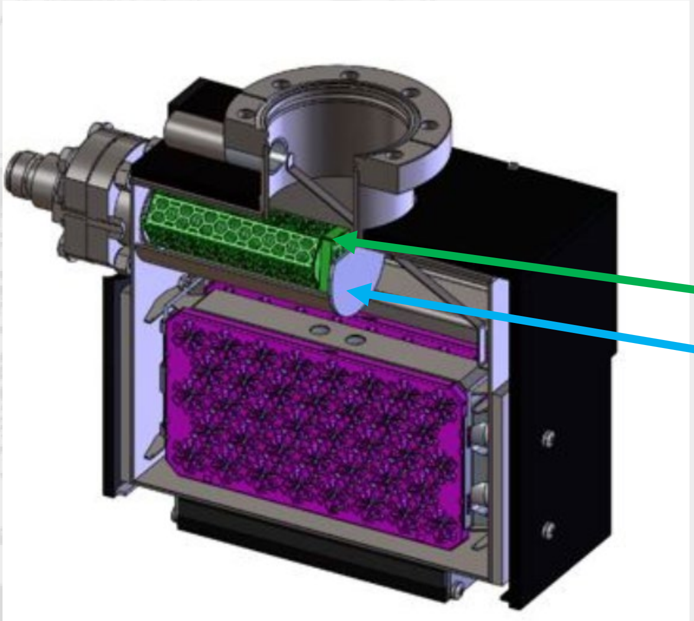
Worked with SAES to get replacement for WP modules

Combined NEG & ion pumps

SAES: add small ion pump to
state of the art NEG (ZAO)

Gamma (Edwards) & Agilent
Add NEGs to ion pump (older material NEG)

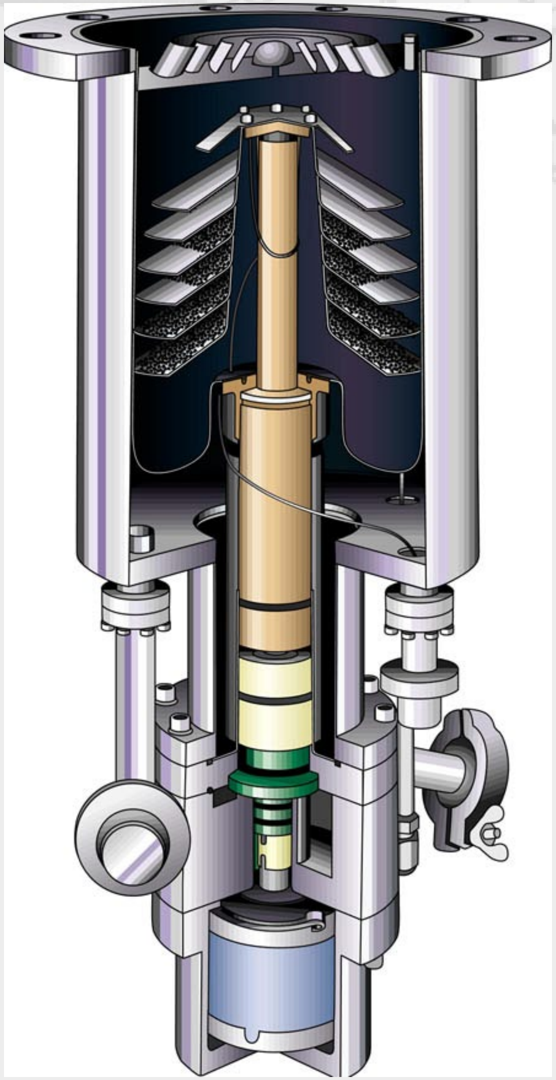
SAES design: NEG, small Ion pump



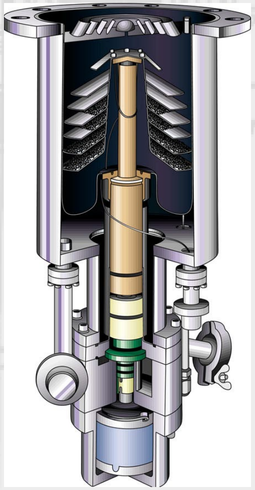
Agilent design with
NEG and
particulate shield added

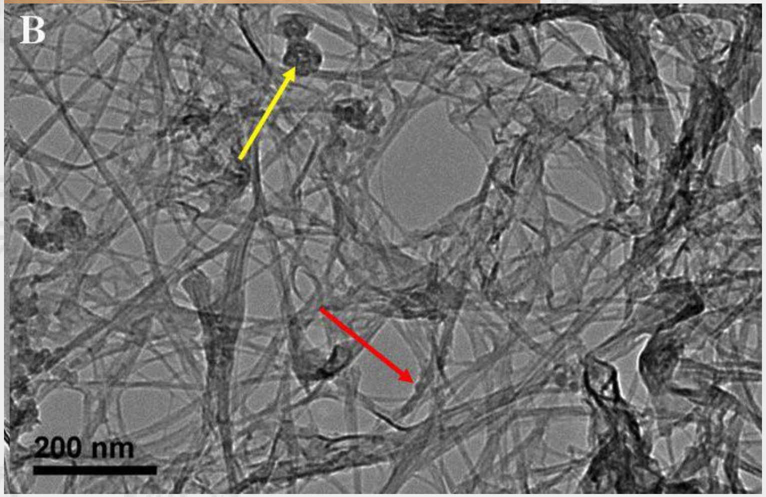
New cryosorber: Nanomaterial

- Typical cryopumps glue charcoal to cold surface
  - Large surface area allows cryosorption rather than cryocondensation
  - Lower pressure
- Requires Low temperature adhesives
  - Can’t bake system well



New cryosorber: Nanomaterial





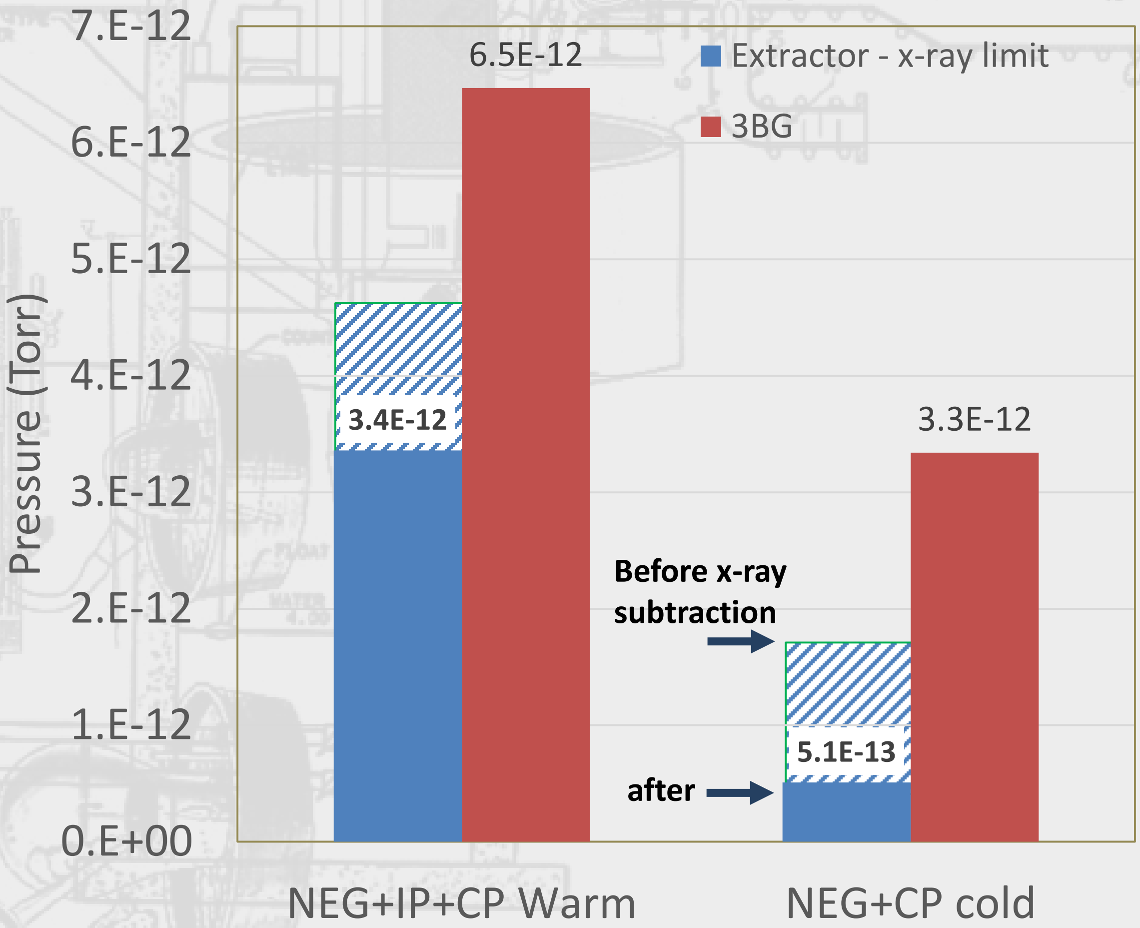
- Boron-Nitride Nanotubes have
  - Huge surface area
  - Good thermal
  - Are freestanding
  - Are manufactured across street (JLab spin-off)
- Can we use these for cryosorber material?

Mounting BNNT for Cryopumping

1 g BNNT material
Copper grid

~4 g BNNT material
“sewn on” with wires
SULI Student, 2016

Results

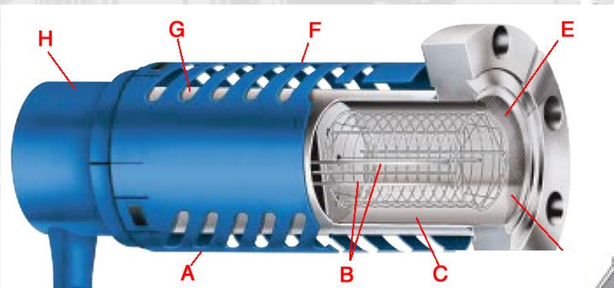


- BNNT outgassing low
  - No valve
  - P~$3x10^{-12}$ Torr BNNT warm
- Cryopump reduces pressure
- x-ray limit $1.2x10^{-12}$ Torr dominates extractor gauge reading
- 3BG readings still have good signal:background, negligible x-ray effect

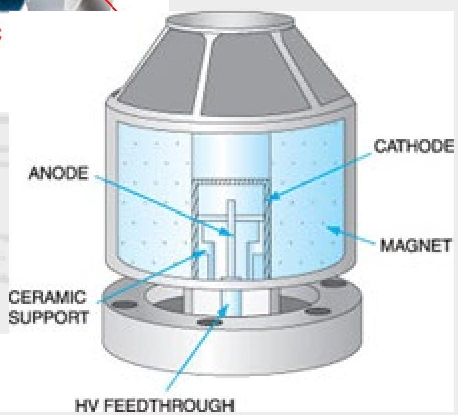
Marcy Stutzman, Roy Whitney and Kevin Jordan “Nano-materials for adhesive-free adsorbers for bakable extreme high vacuum cryopump surfaces” Patent US9463433B2

High/Ultra High Gauges

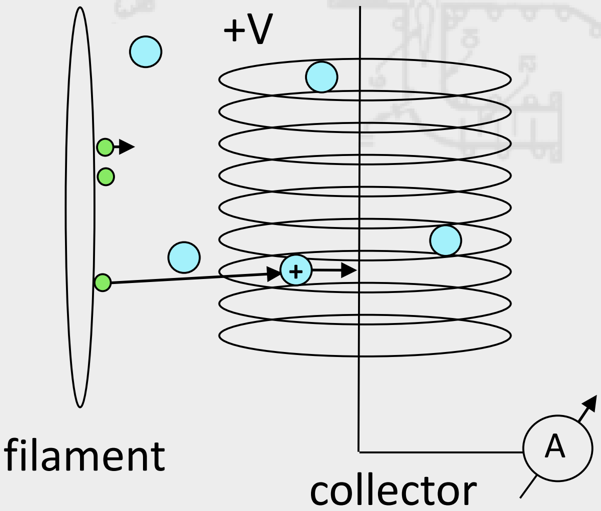
Bayard-Alpert Gauges



Stabil-Ion gauge



Cold Cathode gauge



- Lowest pressures:

  10^{-8} Torr – 10^{-11} Torr

  up to $4,000

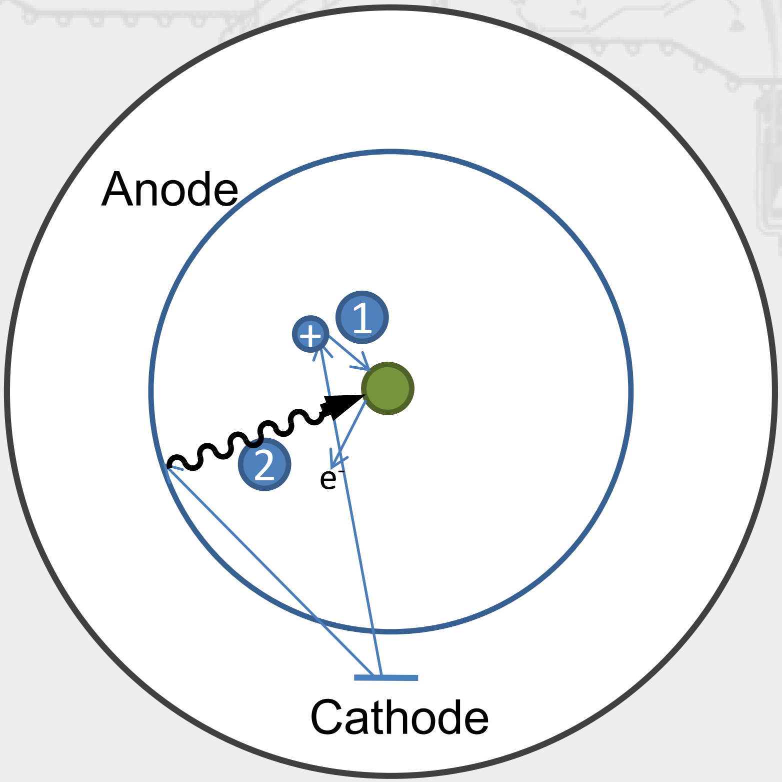
Jefferson Lab

Measure Pressure:
Hot cathode gauge operation and errors

1. True gas ionization
   - Positive current
2. X-ray effect
   - e- on anode -> photons emitted
   - Photons on collector -> electrons emitted
   - Extra positive current

Additional effects:

3. Inverse X-ray effect
4. Electron Stimulated Desorption



$$I^{+} = I_{real} + I^{-}_{x-ray} - I^{-}_{inv.x-ray} + I_{ESD}$$

Ionization gauge pressure calibration

- Chamber evacuated
- Gauge energized
- Current measured
- Calibration factor to translate measured current to pressure

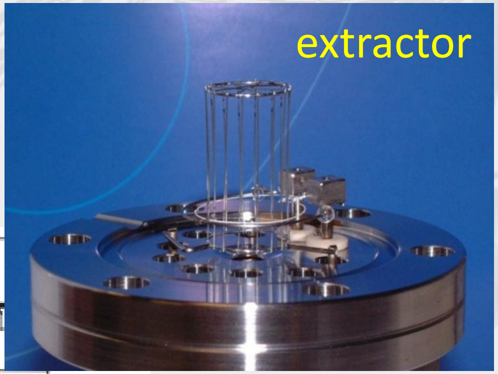
$$P = \frac{\textbf{\textit{ion current}}}{\textbf{\textit{Sensitivity}} * \textbf{\textit{emission current}}}$$

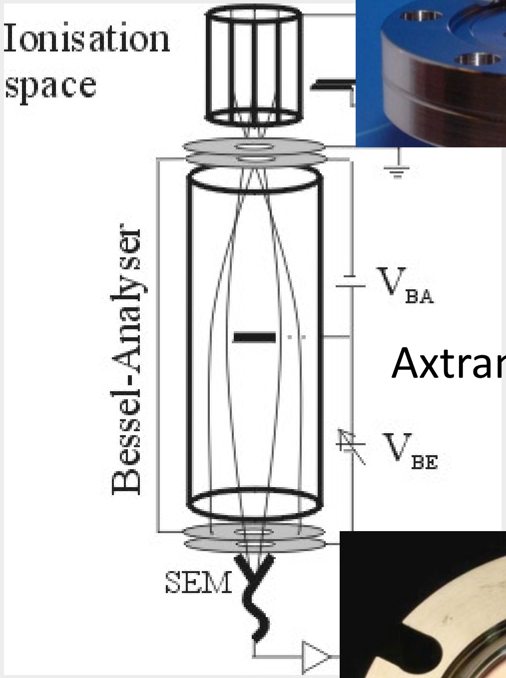
- x-ray limit determines lowest pressure that can be measured

XHV gauges: reduce x-ray limit

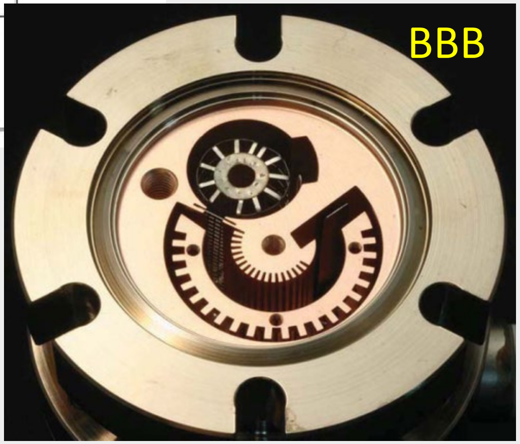
Hot filament

- Extractor gauge
  - available commercially for decades
  - x-ray limit reduced through geometry
  - x-ray limit quote: **$7.5x10^{-13}$ Torr**
  - $4,300
- Axtran gauge
  - Bessel box energy discrimination
  - electron multiplier to assist in low current measurements
  - Quoted limit: **$3.75x10^{-13}$ Torr**
  - $7,500
- Watanabe BBB (Bent Belt Beam) gauge
  - Uses Leybold IE540 controller
  - 230° deflector BeCu housing
  - JVSTA **28**, 486 (2010)
  - Quoted limit: **$4x10^{-14}$ Torr**
  - $13,000 + Ext. controller ($2,600)

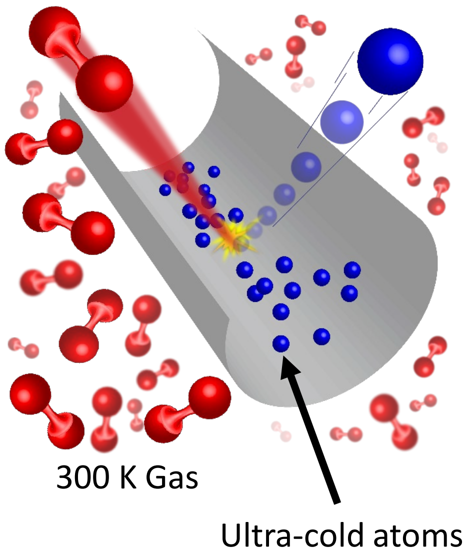




Axtran



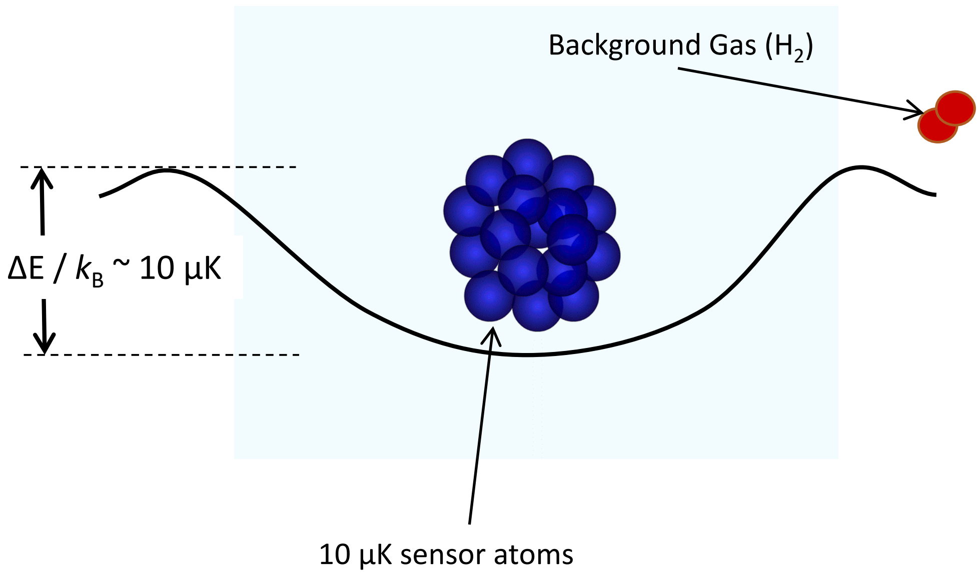
Cold Atom Vacuum Standard (CAVS)



- World's only absolute UHV/XHV sensor and standard
- Cover range of 10^{-10} to 10^{-5} Pa
  - Presently no primary standards
- Move from classical to quantum based standard
- Two Versions: Lab Scale
  Miniature (portable) scale

Thanks to Julia Scherschligt and Jim Fedchak

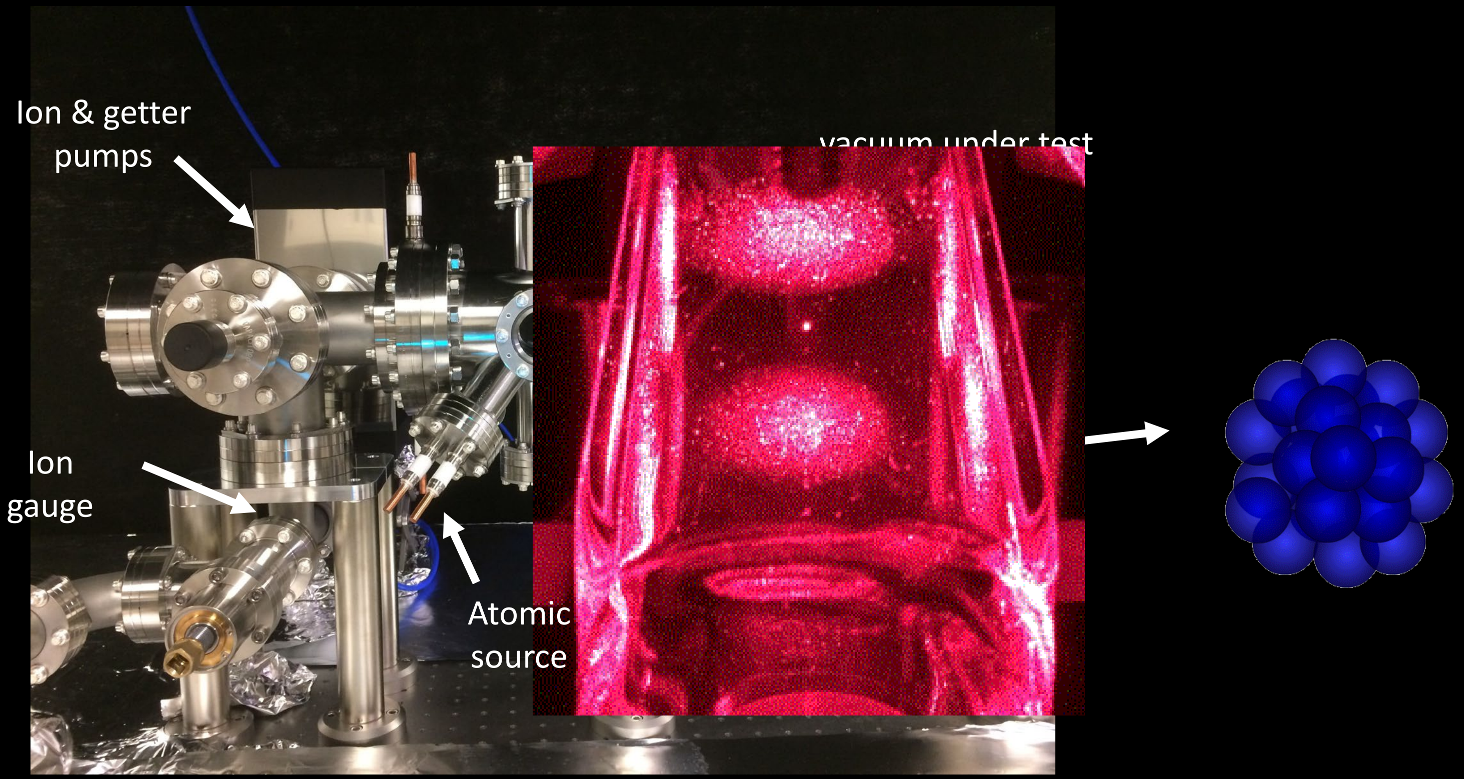
Ultra-cold atoms make ideal vacuum sensors



- Laser cool sensor atoms to ~10 μK
- Transfer cold atoms to shallow magnetic trap
- 300 K background atoms easily kicks 10 μK atoms from magnetic trap
- **Loss rate of cold-atoms is a measurement of vacuum**

Depends on:
- Collision rate coefficient (atomic property)
- Density of background gas

Basis of the CAVS



p-CAVS
Consumer usable quantum gauge

Benefits:

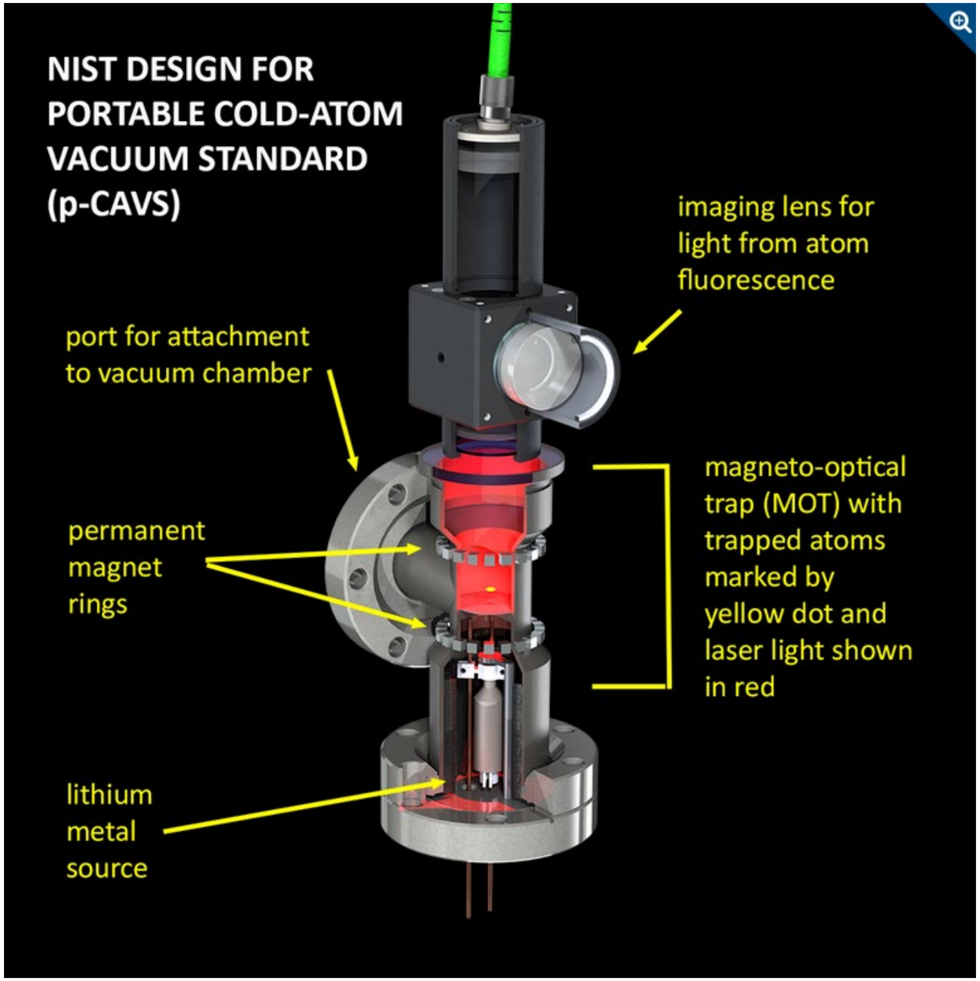
Quantum standard pressure measurement

Cross compare to hot filament gauges

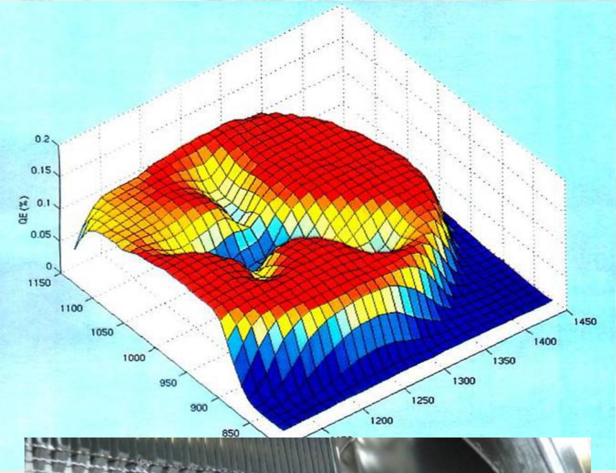
Current status:

Background pressure from Li source limits base pressure ~10^{-10} Torr

Potential Li contamination of chamber



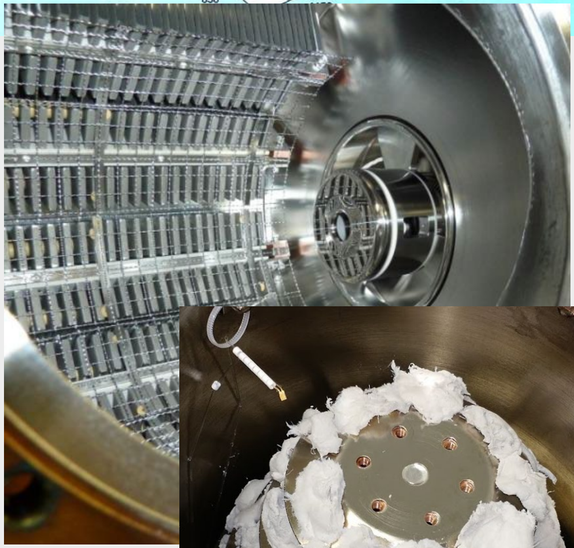
Summary



- High polarization photocathodes require vacuum near or at XHV for long lifetime

- We're optimizing the existing pumps and innovating on new XHV pumping

- Current ionization gauges may be supplemented by Quantum standards and gauges



Questions?